

WHAT IS CLAIMED IS:

- 1 1. A double-gimbaled micromachined mirror structure for parallel-plate
2 electrostatic operation, said mirror structure comprising:
 - 3 a substrate;
 - 4 a mirror;
 - 5 a gimbal around said mirror; and
 - 6 a plurality of folded longitudinal gimbal hinge structures at four positions on a
7 gimbal ring, a first pair of said folded longitudinal gimbal hinge structures connecting said
8 mirror to said gimbal and a second pair of said folded longitudinal gimbal hinge structures
9 connecting said substrate to said gimbal.
- 2 2. The apparatus according to claim 1 wherein each said folded
longitudinal gimbal hinge structure is compound.
- 3 3. The apparatus according to claim 1 wherein each said folded
longitudinal gimbal hinge structure is simple.
- 4 4. The apparatus according to claim 1 wherein each said folded
longitudinal gimbal hinge structure is disposed symmetrically with respect to an opposite
hinge structure.
- 1 5. The apparatus according to claim 1 wherein each said folded
2 longitudinal gimbal hinge structure disposed asymmetrically with respect to an opposite
3 hinge structure.
- 1 6. The apparatus according to claim 1 wherein said mirror is round.
- 1 7. The apparatus according to claim 1 wherein each said folded
2 longitudinal hinge structure is formed of stacked folded longitudinal hinges.
- 1 8. The apparatus according to claim 1 wherein said folded longitudinal
2 gimbal hinge structures attached to the gimbal are recessed into the mirror.
- 1 9. In a double-gimbaled micromachined mirror structure for parallel-plate
2 electrostatic operation, a simple gimbal hinge at four positions on a gimbal ring, each simple
3 gimbal hinge comprising:

4 a plurality of torsional hinge elements arranged in an array parallel to a
5 longitudinal axis of rotation, said hinge elements being linked together in serpentine fashion
6 by rigid braces at ends of said hinge elements;

7 a first external connection point disposed off-center from the lateral edge of
8 the array on a first side of the longitudinal axis of rotation; and

9 a second external connection point disposed off-center from the lateral edge of
10 the array on a second side of the longitudinal axis of rotation.

1 10. The apparatus according to claim 9 wherein:

2 said hinge elements are of the same thickness as said rigid braces;

3 said hinge elements have an aspect ratio of thickness to the width of the rigid
4 braces of at least one; and wherein

5 said hinge elements are of a length which is substantially greater than width
6 and height of each said hinge element.

1 11. The apparatus according to claim 9 further including shock
2 compensation gaps between selected adjacent moveable elements and etch compensation
3 material in said hinge elements and said rigid braces.

4 12. The apparatus according to claim 9 wherein said first external
connection point of a first simple gimbal hinge is connected on the same side of said
longitudinal axis as said first external connection point of a second opposing simple gimbal
hinge to form a symmetrically connected gimbal mirror structure.

1 13. The apparatus according to claim 9 wherein said first external
connection point of a first simple gimbal hinge is connected on the opposite side of said
longitudinal axis as said first external connection point of a second opposing simple gimbal
hinge to form an asymmetrically connected gimbal mirror structure.

1 14. The apparatus according to claim 9 wherein said hinge structures
2 attached between the mirror and the gimbal are recessed into the mirror.

1 15. In a double-gimbaled micromachined mirror structure for parallel-plate
2 electrostatic operation, a simple gimbal hinge at four positions on a gimbal ring, each simple
3 gimbal hinge comprising:

4 a plurality of torsional hinge elements arranged in an array parallel to a
5 longitudinal axis of rotation, said hinge elements being linked together in serpentine fashion
6 by rigid braces at ends of said hinge elements;

7 a first external connection point disposed on a first cantilever element at the
8 longitudinal axis of rotation; and

9 a second external connection point disposed on a second cantilever element at
10 the longitudinal axis of rotation on an opposing side of said array.

1 16. The apparatus according to claim 15 wherein a plurality of said simple
2 gimbals are joined at said connection points in series along said longitudinal axis to form
3 a stacked hinge structure.

4 17. The apparatus according to claim 15 further including shock
5 compensation gaps between selected adjacent moveable elements and etch compensation
6 material in said hinge elements and said rigid braces.

7 18. A double-gimbaled micromachined mirror structure for parallel-plate
8 electrostatic operation, said mirror structure comprising:

9 a substrate;

1 a mirror;

2 a gimbal around said mirror; and

3 a plurality of stacked gimbal hinge structures at four positions on a gimbal
4 ring, a first pair of said stacked gimbal hinge structures connecting said mirror to said gimbal
5 and a second pair of said stacked gimbal hinge structures connecting said substrate to said
6 gimbal.

7 19. In a double-gimbaled micromachined mirror structure for parallel-plate
8 electrostatic operation, a stacked gimbal hinge structure at four positions on a gimbal ring,
9 each stacked gimbal hinge structure comprising:

1 a first gimbal hinge, said first gimbal hinge including:

2 a first plurality of torsional hinge elements arranged in a first array
3 parallel to a longitudinal axis of rotation, said first hinge elements being linked together in
4 serpentine fashion by first rigid braces at first ends of said first hinge elements;

5 a first external connection point disposed on a first cantilever element
6 at the longitudinal axis of rotation; and

10 a second external connection point disposed on a second cantilever
11 element at the longitudinal axis of rotation on an opposing side of said first array; and
12 a second gimbal hinge, said second gimbal hinge including:

13 a second plurality of torsional hinge elements arranged in a second
14 array parallel to the longitudinal axis of rotation, said second hinge elements being linked
15 together in serpentine fashion by second rigid braces at third ends of said second hinge
16 elements;

19 a fourth external connection point disposed on a fourth cantilever
20 element at the longitudinal axis of rotation on an opposing side of said second array;

21 wherein said external connection point is at said third external connection
22 point and said third cantilever element is an extension of said second cantilever element.

20. The apparatus according to claim 19 wherein each said gimbal hinge is
2 compound.

21. The apparatus according to claim 19 wherein each said gimbal hinge is
2 simple.

1 22. In a double-gimbaled micromachined mirror structure for parallel-plate
2 electrostatic operation, a compound gimbal hinge at four positions on a gimbal ring, each
3 compound gimbal hinge comprising:

4 a first plurality of first torsional hinge elements arranged in a first array
5 parallel to a longitudinal axis of rotation, said first hinge elements being linked together in
6 serpentine fashion by first rigid braces at ends of said first hinge elements;

7 a second plurality of second torsional hinge elements arranged in a second
8 array parallel to the longitudinal axis of rotation, said second hinge elements being linked
9 together in serpentine fashion by second rigid braces at ends of said second hinge elements;

10 a U-shaped brace connected at a first end to said first array and at said second
11 end to said second array for form a compound hinge structure;

12 a first external connection point to the first array disposed adjacent to and on a
13 first side of the longitudinal axis; and

14 a second external connection point to the second array disposed at the lateral
15 edge of the second array on a second side of the longitudinal axis.

1 23. The apparatus according to claim 22 wherein a plurality of said
2 compound gimbal hinges is joined at said connection points in series along said longitudinal
3 axis to form a stacked hinge structure.

1 24. The apparatus according to claim 22 further including shock
2 compensation gaps between selected adjacent moveable elements and etch compensation
3 material in said hinge elements and said rigid braces.

1 25. The apparatus according to claim 22 wherein said first external
2 connection point of a first compound gimbal hinge is connected on the same side of said
3 longitudinal axis as said first external connection point of a second opposing compound
4 gimbal hinge to form a symmetrically connected gimbal mirror structure.

1 26. The apparatus according to claim 22 wherein said first external
2 connection point of a first compound gimbal hinge is connected on the opposite side of said
3 longitudinal axis as said first external connection point of a second opposing compound
4 gimbal hinge to form an asymmetrically connected gimbal mirror structure.

1 27. The apparatus according to claim 22 with etch compensation wherein
2 selected ones of said rigid braces have a width greater than adjacent elements.

1 28. The apparatus according to claim 17 with etch compensation wherein
2 selected ones of said rigid braces have a width greater than adjacent elements.

1 29. The apparatus according to claim 24 with etch compensation wherein
2 selected ones of said rigid braces have a width greater than adjacent elements.